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METHOD FOR CONSTRUCTING AND CONNECTING OPTICAL COMPONENTS, PARTICULARLY,
OPTICAL COMPONENTS IN A LASER RESONATOR, AND LASER RESONATOR USED IN THIS
PROCESS

[Verfahren zum Aufbauen und Verbinden von optischen Komponenten,
insbesondere von optischen Komponenten in einem Laserresonator, und bei
diesem Verfahren verwendeter Laserresonator]

Joachim Dudel, et al.

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INVENTOR	(72) : DUDEL, JOACHIM; MEHNERT, AXEL; HALLDORSSON, THORSTEINN
APPLICANT	(71) : DAIMLER-CHRYSLER AG
TITLE:	(54) : METHOD FOR CONSTRUCTING AND CONNECTING OPTICAL COMPONENTS, PARTICULARLY, OPTICAL COMPONENTS IN A LASER RESONATOR, AND LASER RESONATOR USED IN THIS PROCESS
FOREIGN TITLE	[54A] : VERFAHREN ZUM AUFBAUEN UND VERBINDEN VON OPTISCHEN KOMPONENTEN, INSBESONDERE VON OPTISCHEN KOMPONENTEN IN EINEM LASERRESONATOR, UND BEI DIESEM VERFAHREN VERWENDETER LASERRESONATOR

The invention relates to a method for constructing and connecting optical components, particularly, optical components in a laser resonator and a laser resonator used in this process.

Numerous design forms of laser resonators are known to the art based on the state of the art which are predominantly produced with structural components that are precision engineered. As a rule, adjustment units for, at least, four axes are used for the individual functional elements of the laser resonator. Two axes stand vertically in relation to the resonator axis in the Z-axis and allow for a displacement of the functional element. Moreover, two tilted axes to this Z-axis must be realized. The individual adjustment axes now have to be independent of one another and are moved with finely threaded screws due to the required precise adjustment, whereas the angle has to be <1 mrad. To generate resetting forces, springs of different designs are predominantly used.

From DE 3836287 of the Applicant, a configuration example of a state-of-the-art laser is known to the art, the laser resonator of which is a cylindrical metal tube in which the resonator components are rotation-symmetrically directly displaceably arranged by means of bearing and guide components, and can be adjusted and fixated by means of adjustment screws.

* Number in the margin indicates column in the foreign text.

A similar configuration example is disclosed by EP 0251718A2 with the example of an optically pumped laser in which the individual components are arranged with a specific distance in a transportation structure.

Such laser conceptions exhibit a number of disadvantages; in particular, the expenditures are much too high for their production, weight, and structural size. Thus, for instance, it is necessary to only use fine threadings which require hardened inlets as bearing surfaces, necessitate anchors for the return springs, and call for precision-engineered bearing surfaces for the spheres - which define the tilted axes. An additional grave disadvantage is that an automation of the laser adjustment and laser production is not possible. Until now, the adjustment of these kinds of laser resonators has always only been manageable by hand. Nor can the structural size be reduced as desired because the laser head volume in all spatial directions cannot be minimized, or can only be minimized very insignificantly in these conceptions.

However, in the previously described state-of-the-art conceptions, the negative influences of environmental conditions and the system's inherent thermal behavior are of impact. The structural elements of the laser resonators are always subject to changing environmental conditions, particularly, if they are the sub-system of a "consumer product" - as, for instance, in transportation and storage - and thus depart from the organized conditions of a laser laboratory. Mechanical stress, such as shaking and concussion, is added to this. The adjustment elements, as

they are called above, are as poorly suited as they can be to withstand all of these stresses. On the one hand, this is due to the fact that a great amount of material must be used to bring about a complete decoupling of the adjustment levels with such adjustment elements.

Therefore, due to the thermal expansion coefficients, temperature changes can lead to great maladjustments. On the other hand, in the event of concussions acting upon such structures, the static frictional forces between the components must be overcome. Thereafter, the adjustment /2 level concerned "slides" into a new position and remains there. The return forces and directions of the springs are not capable of restoring the original condition. Hence, the resonator must be manually readjusted.

With regard to the thermal behavior of the state-of-the-art configuration examples, it should still be mentioned that, as is a known fact, a laser resonator only partially converts the coupled primary output (for instance, the optical output) into useful radiation. Depending upon the laser conception, this is between 10% and 50%. A large part of this must be withdrawn from the functional elements of the resonator via heat conduction because, otherwise, an overheating and, hence, a partial destruction of the elements is caused. However, with the use of the previously mentioned adjustment elements, a heat withdrawal via the structural elements is associated with great leaps in temperature because the individual adjustment levels are only connected via punctiform bearing surfaces and, thus, extremely great thermal resistances occur. Of course, the thermal transient behavior in the actuation process which, due to

the great thermal resistances, exhibits high time constants is also dependent on this. With high stability requirements set in the resonator, these time constants may then even be in the range of several minutes.

To build up optical functional groups, particularly, laser resonators, modern connection techniques are used, such as soldering and agglutination methods. The optical components are adjusted in a close contact to holding structures, adhesives or solder are introduced into the created gap before or after the adjustment, and the connection process which, in most cases, is thermally induced, is carried out afterwards.

The advantage of this technique is the reduced expenditure for mechanical positioning devices, the improved thermal contact to the holding elements, and the higher stability of the connection. The grave disadvantage of this connection technology is the maladjustment of the elements during the hardening process, however. These advantages can be compensated in that, for instance, during soldering, an appropriate delay in the hardening process is kept. However, this process is extremely elaborate in the production and only difficult to automate.

Among the adhesives, e.g., slow-curing epoxy resins can be used, whereas maladjustments which arise are continuously compensated during the hardening time that, in most cases, lasts for hours. While this process is automatic, the production of a resonator blocks the production facility for hours, however.

The present invention is based on the objective of largely eliminating the disadvantages of the state of the art, and to create a laser resonator

of the type mentioned at the beginning of the text which is free of maladjustments due to thermal or environmental influences while also guaranteeing an economically optimized production.

This objective is realized by means of the measures that are shown in Claim 1. Advancements and configurations of the invention are specified in the Sub-Claims.

In the following text, the invention will be explained in greater depth by means of the description of preferred configurations in conjunction with the drawings.

Shown are:

Figure 1, a schematic representation of a whole system in accordance with the invention using the example of a Nd:YAG laser frequency coupler,

Figure 2, a schematic representation of the sphere plate resonator with only spherical holders for the laser resonator elements.

Figure 3, a top view with a longitudinal sectional view /3
of a configuration example of a holding element for the laser crystal with a spherical surface,

Figure 4, a top view and a longitudinal sectional view of a configuration example of a first crown element,

Figure 5, a schematic representation of a configuration example of a second crown element with a holder for the optical element,

Figure 6, a schematic representation of a configuration example of a tubular resonator carrier in accordance with the invention,

Figure 7, a schematic representation of a cross-section of an additional tubular resonator carrier in accordance with the invention, and,

Figure 8, a "sphere-rail concept" in accordance with the invention for producing optical systems.

In accordance with the invention, the previously required elaborate state-of-the-art adjustment elements are replaced by structural components which are easily serially produced that, on the one hand, form a simple optical bank and, on the other hand, form a connection which is adjustable in several axes for the optical components. Soldering and agglutination techniques are options for the connection process, however, in particular, fusing by means of laser irradiation is an option. Individual structural elements, especially parts of the connection, are configured so that a subsequent fine adjustment of the created hardening delay is, above all, made possible by means of fine laser adjustments.

In this process, in the simplest scenario, the fact that sheet metal strips which are irradiated by means of laser energy receive internal tension which brings about a warping of the tip is utilized. Thus, connected optical components can be tilted towards each other and displaced.

A selective readjustment is made possible through the use of a component position sensor system which recognizes the position and tilted angle before and after the connection process. In the simplest case, this sensor system may be the laser beam of an adjusting laser (e.g.,

HeNe laser) which is directed at the surface of the optical component.

Interferometric measuring techniques or image-processing systems are equally conceivable. Moreover, the emitted laser beam of the created resonator itself can be used for a selective readjustment after an appropriate analysis.

Figure 1 depicts a whole system in accordance with the invention.

Generally, in accordance with the invention, it is proposed that the individual optical elements or component groups, such as laser crystal (15) or KTP crystal (14a), resonator mirror (13a), etc., be integrated in spherical or tubular holders (12, 13). Figure 2 depicts a schematic representation of the sphere plate resonator in accordance with the invention with only spherical holders for the laser resonator elements and Fig. 3 shows a top view and a longitudinal sectional view of a configuration example of a holding element for the laser crystal with a spherical surface. These holders (12, 13) are now successively put in a row with each other, adjusted, and kept in an assembly tool (which is not represented here) - similar to an optical bank.

Rectangular oblong support plates (10) of a specific thickness are held by so-called base plates (11) which have various strengths and can thus form any defined distance and may have predefined distances to one another. Appropriate bores (19) in which or at which the spherical or tubular holders (12, 13) are arranged are located on the [cif - error in German - "rauinfrein" does not exist in the German language - it could be typo.] free end pieces of the support plates (10). As can be deduced

from Figs. 1 to 3, the holders (12, 13) that are equipped with the laser resonator elements are set in the respective bore of the pertinent support plate (10) with their spherical or rounded surface, pre-adjusted /4 with the adjusting elements of the assembly tool, and, then, for instance, connected by means of irradiation with a welding laser. During the connection process, for instance, the welded or soldered connection (21) is created in the connection gaps. As a rule, the connection between the holders (12, 13) and their support plates (10), but also from the support plates (10) to the base plates (11) can be produced by agglutination, welding, or a laser welding process.

In the configuration examples in accordance with Fig. 1, the KTP or YAG crystal is fastened on a so-called "crown element" (14) (Fig. 4) which forms an annular retainer that, on the one hand, is equipped with teeth or studs (14a) for the laser adjustment and welding and soldering levels (14c, 14d) in relation to the support plate (10), as well as with the spherical holder (12). The surfaces of the teeth or studs (14a) form the welding or soldering planes (14c) - there are three in the represented configuration example - for the spherical holder (12). The "gaps" between the teeth (14a) are marked with (14b). As already mentioned - the pre-adjustment of the individual resonator elements is handled by the assembly tool which is not shown. The post-adjustment in the X and Y directions but after the laser welding, soldering, or agglutination process, is carried out by means of appropriate laser beam irradiation on one or several of the teeth (14a) of the crown element (14). Due to

the time-appropriate irradiation, the respective tooth experiences a certain bend which is utilized for a precise final adjustment. As practice has shown in the example of a post-adjustment by means of Nd:YAG laser beam, such a post adjustment not only can be made very precisely, but also very rapidly. As a rule, the z-axis does not require an exact adjustment.

In an additional configuration example, the spherical holder (10 or 11) is taken up by a "snap crown element" with the laser resonator element, as shown sketched in Fig. 5. Here, radiuses are ground into the insides of these teeth (114a) of the crown element (114), which correspond with those of the spherical holder (12) or the holders with a spherical surface (13). As practice shows, it is not a problem to position these holders (12, 13) between teeth or studs (114a) which spread slightly during the insertion. What is thereby achieved is that no pressure is needed to press the holders (12, 13) on any more.

Now, it may be desirable with various configurations that the holder is merely set, welded, or soldered in a disc (13b) which is equipped with an appropriate bore. Through an upward or downward, or lateral, displacement of this disc over the bore of the support plate (10), it is now possible without a problem to achieve congruence with the laser beam axis (20). Because such displacements only require relatively short distances, they can occur during the time when the adhesive connections dry.

The support and base plates (10, 11) can be equipped with cooling channels for fluid systems without a problem, but can also be coupled with Peltier elements without any problem.

The problemless construction of a solid-state laser resonator, e.g., of a frequency-doubled Nd:YAG laser is now disclosed through the above described measures in the simplest manner which facilitates the construction of small and lightweight lasers.

The manufacturing costs for the individual components (plates and connections) are substantially reduced because these parts get by with nearly no manufacturing tolerances. Due to the extremely short times during the connection process (laser welding) and the selective (post)-adjustment process of the welding delay, the shortest /5 manufacturing times are made possible. Thus, the construction and connection technique concept for laser resonators described here is ideally suited for the mass production of optical systems which consist of several elements to be adjusted.

In the following text, a second configuration example is described for the above-described construction and adjustment technique (Fig. 6).

The configuration example in accordance with Fig. 6 is particularly suitable for the construction of optical systems from components of high homogeneity and quality. A connection for the retainer adjustment of the components can be eliminated here. The components are retained in bushings (211), inserted into a tubular structure (210), and aligned distance-wise, whereupon the bushings (211) are connected with the tubes

(210). The final adjustment of the elements is carried out on the studs (213) intended for this process by means of laser bending. The emitted beam of the laser resonator is analyzed in this process (e.g., output, quality of beam, noise) and serves as a controlled variable for a selective final adjustment. For passive optical systems (e.g., lens systems), a regulating signal from the image of a test beam, or an image, can be used.

As illustrated in Fig. 6, a specific structural tube (210) is used as a carrier for the optical elements (here, elements of a laser resonator), whereas these elements are integrated in bushings (211) which are fitted to the diameter of the tubes (210) which are inserted at predefined distances to one another. As a result, the position alignment of the resonator elements is defined, the tube (211) forms an optical bank. By means of suitable connection techniques, e.g., laser welding, the bushings (211) are thereupon connected with the tube (210). Now the tube (210) exhibits slots (212) and recesses (214) for a fine adjustment, whereas the slots (212) form defined studs (213). The adjustment is carried out by bending the tube (210), whereas, for a final adjustment, a plastic deformation is required which, while it can be carried out mechanically, in accordance with the invention, as a rule, occurs by means of laser irradiation on the studs (213) which is carried out at a predefined output and irradiation time. The illustrated structural setup of the tube (210), in the present case, the thin axial studs (213), facilitate the desired collapsing or tipping as a result of the laser pulses. An xy-displacement can additionally be realized through opposed bends with a local distance.

Figure 7 illustrates an additional configuration of a tubular resonator carrier in accordance with the invention in which the precision or final adjustment is carried out by means of a deformation of the tube (2110). Here, the optical resonator elements are also integrated in bushings (2111) which are configured as described above, and are integrated in tubes (2110). Here, slots (2112) and recesses (2114) are also arranged for the structural setup and a lighter weight of the resonator. Here, the wound plastic deformation of the resonator is realized through laser irradiation on the studs (2113) which extend obliquely in relation to the tube's axis (A).

A third configuration example is shown in Fig. 8. In the configuration example in accordance with the invention that is shown here, the individual optical elements, e.g., of the solid-state laser to be conceptualized, meaning the laser crystal, the KTP crystal, and the resonator mirror, are integrated into spherules or tubes. These elements are now aligned in relation to one another and kept adjusted with appropriate adjustment devices - for instance, XYZ tables, rotary tables, or goniometers - as desired, i.e., according to the predefined conditions of the desired /6 optical functional group (e.g., of the laser resonator). Subsequently, the spherules (30) or tubes are connected with each other with one or several rails (31) each - whereas U-shaped rails are best. By means of two opposite rails, an optimal stability is already provided. The next sphere element is then connected with rails which are 90° offset in relation to the above-mentioned sphere element.

The connection between the sphere element (30) and the rail (31) can be made in the standard way by agglutination, soldering, or a laser welding or soldering process. This "sphere-rail" concept for the production of adjusted optical systems (e.g., laser resonators) guarantees the serial production of solidly adjusted reasonably priced resonators.

The compensation of the delay in the hardening process, in turn, is realized through laser adjustments; for this purpose, the rails (31) are appropriately equipped with bending beams.

Patent Claims

1. Method for constructing and connecting optical components, particularly, optical components in a laser resonator with the steps:

Putting each optical component (12a, 13a, 15) on holders in a retainer element (12, 13, 211, 2111, 30) which is a part of a joint with up to six degrees of freedom;

adjusting the optical components (12a, 13a, 15) in relation to one another by means of external assembly tools, so that the optical function of the system results and all parts of the joint come into a mechanical contact, and a contact is created to an optical bank (10, 11, 210, 2110, 31);

determining the position of the optical components (12a, 13a, 15) prior to a connection process through a component sensor system;

connecting all components (10, 11, 12, 13, 210, 211, 2110, 2111, 30, 31) by means of an agglutination, soldering, or welding technique,

determining the position of the optical components (12a, 13a, 15) after the connection process by means of the component position sensor system,

detecting the maladjustment of the optical components (12a, 13a, 15) from the position of the optical components (12a, 13a, 15) before and after the connection process by means of the component sensor system; and

compensating the maladjustment of the optical components (12a, 13a, 15) which resulted in the connection process, by means of precision laser adjustment by irradiation of, at least, a part of the connection, in order to make this part bend selectively, whereas the component position sensor system determines the irradiation output and the duration depending upon the detected maladjustment of the optical components, respectively.

2. Method, in accordance with Claim 1, characterized by the step of forming the optical bank (10, 11) by welding individual connections to each other.

3. Method, in accordance with Claim 1 or 2, characterized in that the connection exhibits spherical surfaces and the rotary axes of the assembly device extend through the center of the curvature of the connection's spherical surfaces during the step in which the optical components (12a, 13a, 15) are adjusted.

4. Method, in accordance with any of the Claims 1 to 3, characterized in that, during the adjusting step, the translatory

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axes of the assembly device extend in parallel to the assembly surfaces of the optical bank (10, 11, 210, 2110, 31).

5. Method, in accordance with any of the Claims 1 to 4, characterized in that, during the adjusting step, the mechanical contact between the components is carried out after the adjustment of the process of the assembly tool in the z-axis. [sic - German has some errors in it]

6. Method, in accordance with any of the Claims 1 to 5, characterized in that, during the adjusting step, for adjustments in the z-axis, two parts of the connection are pressed against each other by means of spring force, and the mechanical contact between a part of the connection and a support plate (10) of the optical bank (10, 11, 210, 2110, 31) is produced in this way.

7. Method, in accordance with any of the Claims 1 to 5, characterized in that, during the adjusting step, the mechanical contact between, at least, two components of the connection is kept by means of gravitational force.

8. Method, in accordance with any of the Claims 1 to 5, characterized in that, during the adjusting step, the mechanical contact between a support plate (10) of the optical bank (10, 11, 210, 2110, 31) and of a component of the connection is kept by means of gravitational force.

9. Method, in accordance with any of the Claims 1 to 8, characterized in that, during the step of connecting, the connection process between the components of the connection and a support plate (10)

of the optical bank (10, 11, 210, 2110, 31) is carried out by means of a laser welding technique.

10. Method, in accordance with any of the Claims 1 to 9, characterized in that, in the step of compensating the adjustment by means of precision laser adjustment, surfaces which are provided for this purpose on parts of the connection or the retainer element are irradiated with laser light, the surface is thermally deformed in this process, and this deformation brings about a bending of the surface.

11. Method, in accordance with any of the Claims 1 to 10, characterized in that, through the step of testing the bending behavior of the selectively bent part, whereas the component position sensor system measures the bending behavior as a function of the applied laser energy and the location, the created translatory and sweep vector are determined for this part, and these vectors are used to selectively bring the component back into its position prior to the connection process.

12. Laser resonator with:

optical components (12a, 13a, 15),

retainer elements (12, 13, 211, 2111, 30), whereas each retainer element (12, 13, 211, 2111, 30) is a part of a connection with up to six degrees of freedom, and an optical bank (10, 11, 210, 2110, 31) with which the retainer elements (12, 13, 211, 2110, 30) are in contact and which are adjusted and arranged along the optical components (12a, 13a, 15),

whereas a part (13b, 14a, 114a, 213, 2113, 31) of the connection can be selectively bent by irradiation with a laser beam, and serves to post-adjust the optical components (12a, 13a, 15), whereas the degree of bend depends upon the irradiation output and duration.

13. Laser resonator, in accordance with Claim 12, characterized in that the optical bank (10, 11) is formed by support plates (10) and base plates (11).

14. Laser resonator, in accordance with Claim 12, characterized /8 in that the optical bank (31) is formed by U-rails.

15. Laser resonator, in accordance with Claim 12, characterized in that the optical bank (210, 2110) is formed by a round or square tube.

16. Laser resonator, in accordance with Claim 12, characterized in that the optical bank is formed by individual connections which are welded to one another.

17. Laser resonator, in accordance with any of the Claims 12 to 16, characterized in that the connection provides up to three degrees of freedom of the translation, and, at the same time, up to three degrees of freedom of the rotation.

18. Laser resonator, in accordance with Claim 17, characterized in that each retainer element (12, 13, 211, 2111, 30) exhibits a functional surface for the connection.

19. Laser resonator, in accordance with Claim 17, characterized in that the degrees of freedom of the rotation are realized by means of a (partial) spherical surface of the retainer element (12, 13).

20. Laser resonator, in accordance with Claim 17, characterized in that the degrees of freedom of the translation are realized in that the connection can be displaced along the surface of the optical bank (10, 11) or of the support plate (10).

21. Laser resonator, in accordance with any of the Claims 12 to 19, characterized in that the selectively bendable part (13b, 14a, 114a, 213, 2113, 31) of the connection exhibits irradiation surfaces for laser adjustment.

22. Laser resonator, in accordance with any of the Claims 12 to 21, characterized in that the selectively bendable part (13b) is a disc with a bore.

23. Laser resonator, in accordance with any of the Claims 12 to 21, characterized in that the selectively bendable part (213; 2113) is a round or square tube.

24. Laser resonator, in accordance with any of the Claims 12 to 21, characterized in that the selectively bendable part is the ferule of a glass fiber.

25. Laser resonator, in accordance with any of the Claims 12 to 24, characterized in that the selectively bendable part contains various recesses (14b, 214, 2114) which facilitate the easier and defined bending of the part.

26. Laser resonator, in accordance with any of the Claims 12 to 25, characterized in that the components of the connection and the optical

bank (10, 11) or the support plate (10) are fastened to each other by means of an adhesion, soldering, or laser welding technique.

27. Laser resonator, in accordance with any of the Claims 11 to 26, characterized in that the bendable part (13b, 14a, 214, 114, 31) consists of a thermally deformable material, particularly, of steel, copper, or a thermoplast.

Accompanied by 5 page(s) of drawings

Fig. 1

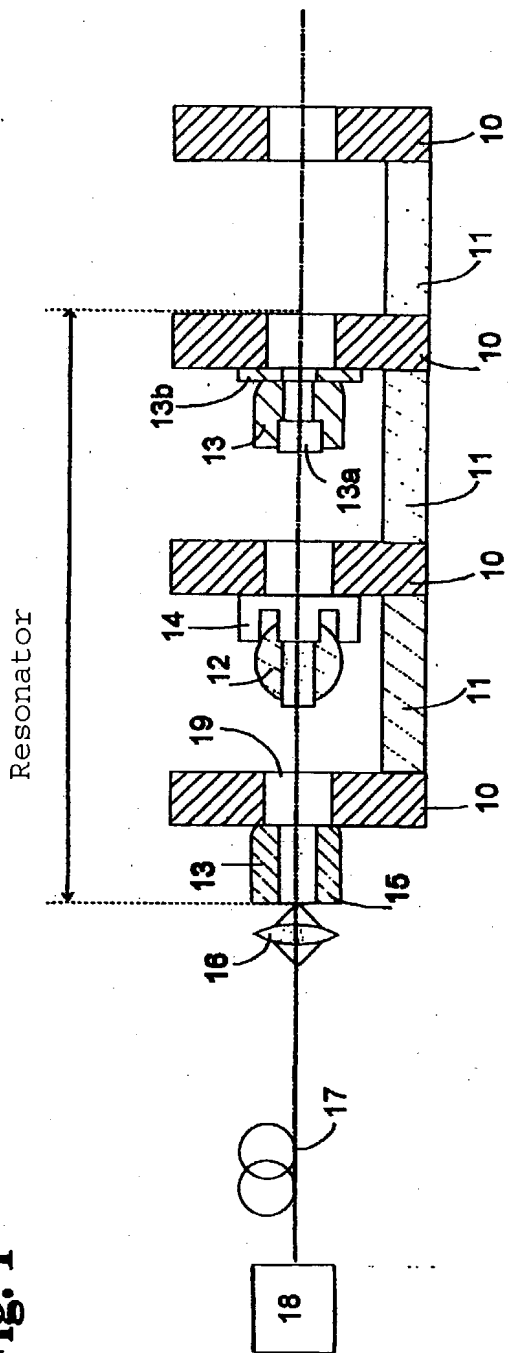


Fig. 2

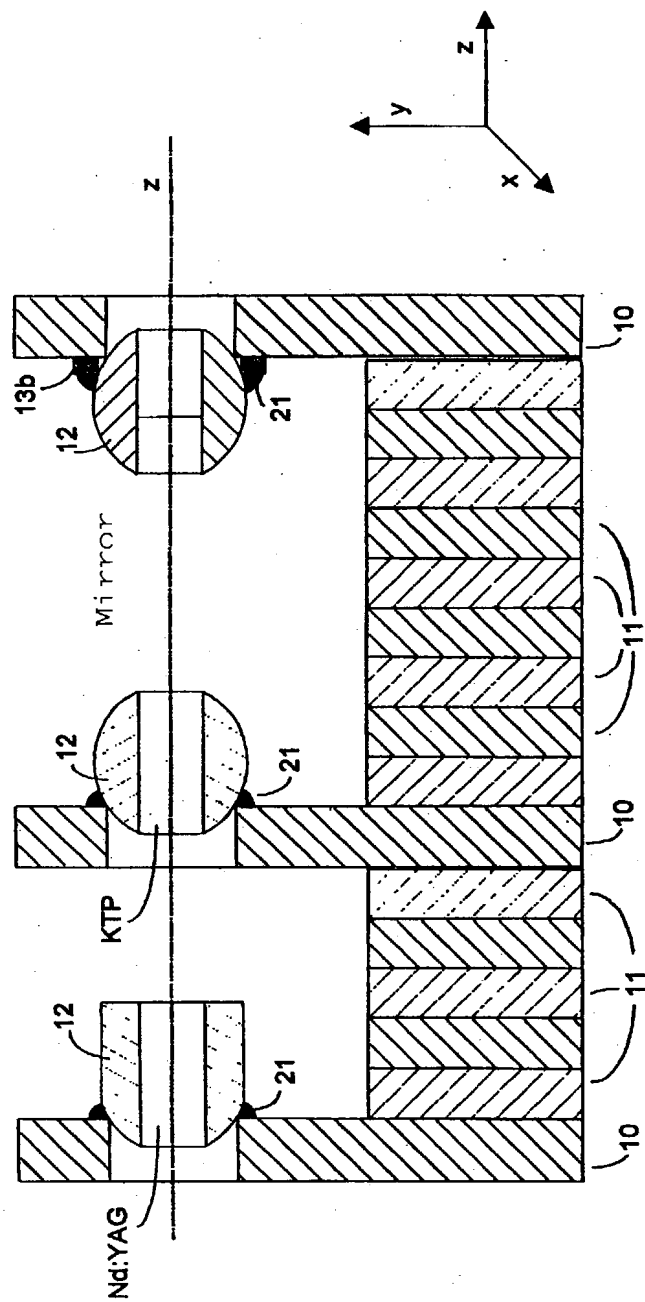


Fig. 3

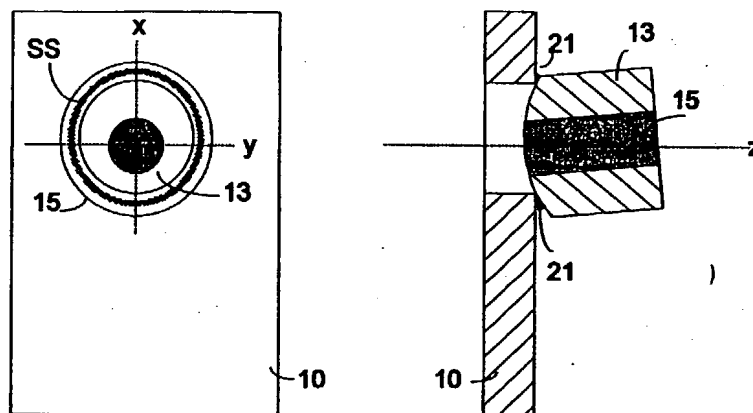


Fig. 4

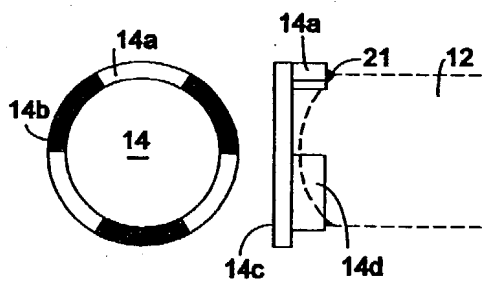
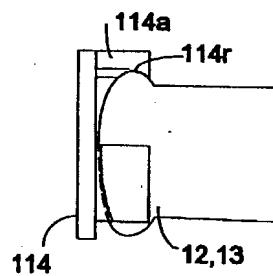


Fig. 5



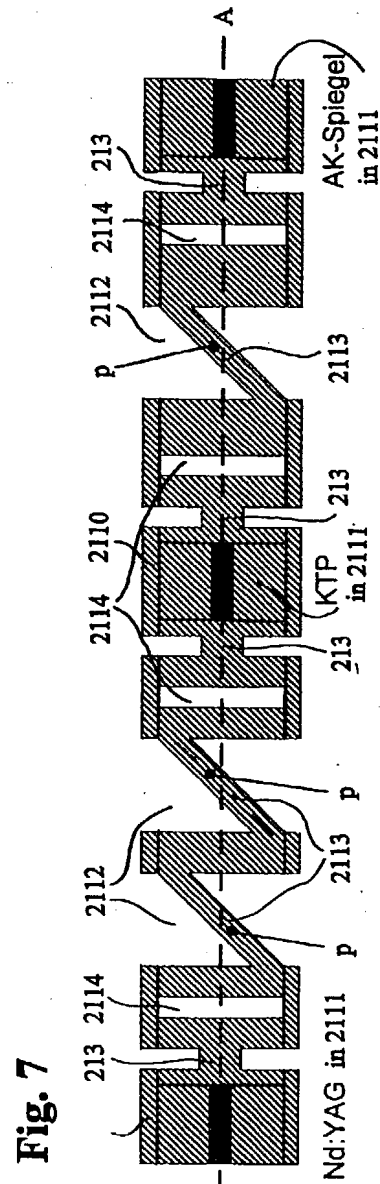
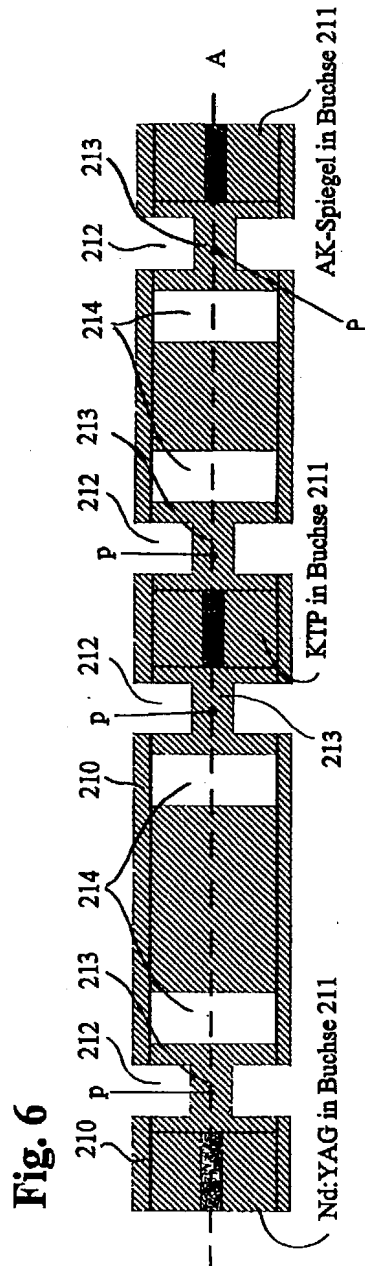


Figure 6
 Nd:YAG in Buchse = Nd:YAG in bushing
 KTP in Buchse = KTP in bushing
 AK-Spiegel in Buchse = AK mirror in bushing

Figure 7
 AK-Spiegel = AK mirror

Fig. 8

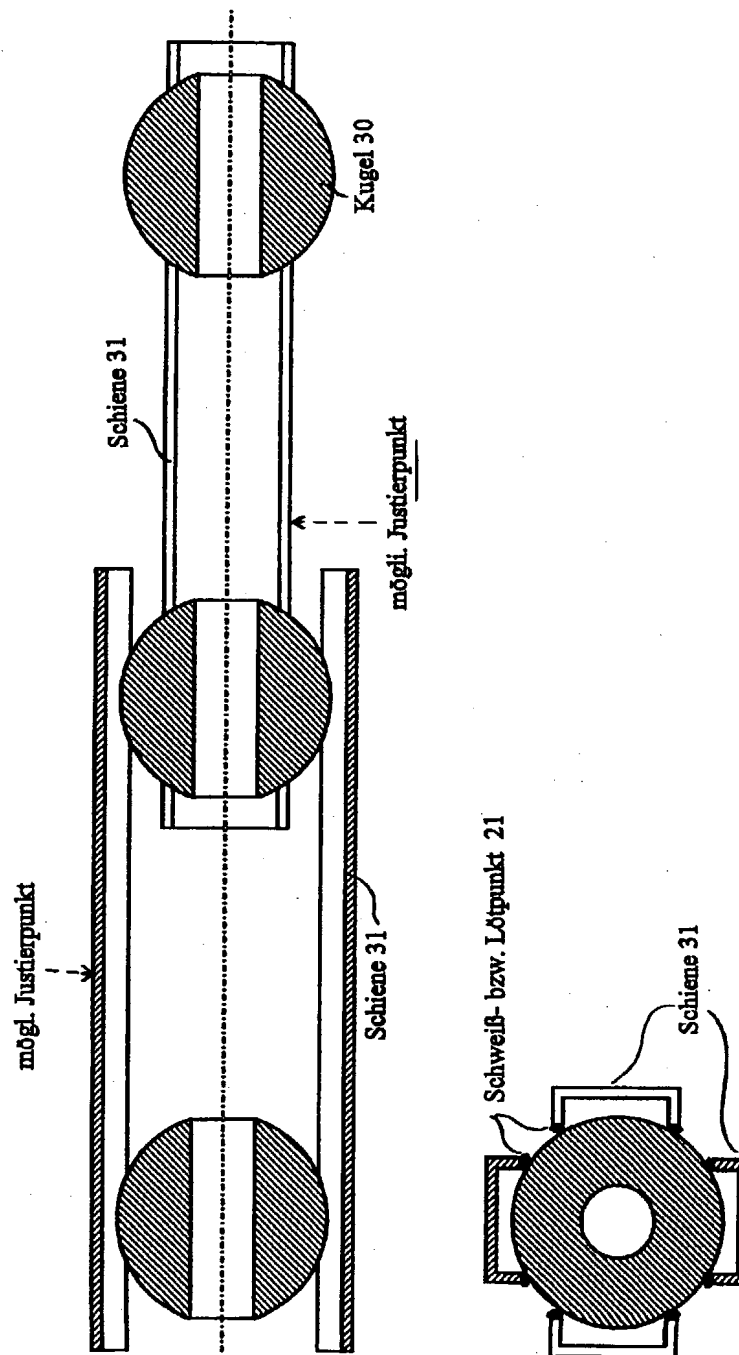


Figure 8

mögl. Justierpunkt = possible adjustment point

Schiene = rail

Kugel = sphere

Schweiß- bzw. Lötunkt = welding or soldering point